# Estimation of the fundamental period of vibration of the dental clinics and the dental classroom of the Catholic University of Cuenca using environmental vibration recordings

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**Abstract.** In the Faculty of Dentistry of the Catholic University of Cuenca, located in the city of Cuenca, province of Azuay. The lecture hall and the clinics of the faculty are built. These structures were built during 2018 and 2019. Due to the seismic events occurred in recent years, monitoring was carried out to obtain the characterization of the dynamic behaviour. The two structures are formed by a structural system based on structural steel frames (beam-column), the structure for laboratory use has metal columns filled with concrete, while the structure for classroom use has metal columns without concrete filling. The main objective was to obtain the vibration periods experimentally from the recording of environmental vibrations and also to obtain them analytically with mathematical models elaborated in structural analysis programs and environmental vibration tests were performed. The results show that building 1, composed by the dentistry clinic, obtained a vibration period of 0.41 s in X and 0.33 s in Y (Analytical Model); and, in the environmental vibration test it showed a period of 0.46 s in X and, 0.30 in Y. Building 2, composed of the dental faculty classroom, obtained periods of 0.53 s in X and 0.29 s in Y (Analytical Model). While in the environmental vibration studies they gave values of 0.52 s in X and 0.26 in Y.

## 1 Introduction

The continuous and incessant occurrence of destructive earthquakes throughout world history has been a frequent source of studies in both seismic engineering and civil engineering. These two disciplines have provided valuable knowledge to construction professionals, who through the fusion of these concepts have given way to the robust development of seismic-resistant structural engineering, a fundamental tool in the design, calculation and construction of buildings that provide greater safety and resistance in the event of a seismic event.[1]

In the circum-Pacific belt and specifically in Ecuador, the Nazca subduction process generates a high seismicity in its path, dip, to the east. Because of this process on the Ecuadorian coast, they have a shallow hypocentre and in the eastern region the seismic events associated with subduction can have focal depths greater than 200 km. In addition to the

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seismic activity associated with subduction, there are earthquakes generated by the seismic activity associated with the subduction zone, there are earthquakes generated by the activation of local geological faults [2].

In general, surface earthquakes cause the most damage. For this reason, it can be indicated that the Ecuadorian coast is the most seismically dangerous, followed by the highlands and finally the east. Therefore, from the seismic point of view, it is not the same to build in the city of Esmeraldas, where the seismic hazard is very high, than in Tena, which has a lower seismic threat [2].

An earthquake occurred in Ecuador on April 16, 2016 with a magnitude of 7.8, devastating towns and cities in the provinces of Manabí and Esmeraldas, causing great loss of human and economic life. Thus proving that structures such as houses and buildings were vulnerable due to several causes, among which are: the magnitude of the earthquake reflected in the response spectra, construction of new floors over existing ones without reinforcing the structures, quite flexible structures that had large displacements, structural typology that requires buildings to have a first floor with a height of 5 m and mezzanines, and amplification of seismic waves due to site effect [3].

Cuenca is a city with a high seismic hazard, vulnerable to earthquakes [4], This would imply that in the event of a seismic event, several structures in the city and therefore the people who occupy them would be in serious danger. There are several causes that make the structures of the city of Cuenca vulnerable, many of them associated with informal constructions, poor quality materials, extensions of structures without any prior evaluation, houses built without complying with current regulations and the lack of control of the constructions by the competent authorities, among others. For these reasons it is of great necessity to evaluate an existing structure in order to have data on its dynamic behaviour in the event of an earthquake and to be able to take actions in terms of reinforcements or to validate the good structural behaviour. This becomes a complex task when there is no previous information such as structural plans, technical specifications and parameters of the structural steel or concrete applied. Based on this background, it is necessary to propose methods that allow us to obtain information of this type of structures, to propose tools that provide us with data of the real dynamic behaviour of an existing structure.

One of the dynamic parameters that has been widely studied worldwide due to its great importance is the vibration period, which is directly related to the stiffness of the building and can be associated with external inputs (acceleration, soil response, materials, construction quality, etc.).[5]

The vibration period is usually obtained analytically, performing the modelling in a structural calculation software, which in some cases this value ends up being a period far from reality because it does not consider the interaction between the structure and the non-structural elements (masonry) and the soil-structure interaction.[6] . As there are several uncertainties in determining the actual seismic response of a structure, generally dominated by the natural period of vibration and the damping coefficient [7] there are other ways to measure it in situ. Generally, excitation methods such as ambient vibration have been used to determine it.

This study proposes the estimation of the fundamental period of vibration of structural steel structures using the ambient vibration technique, since this technique has become the main experimental method available to evaluate the dynamic behaviour at large scale.[8]

## 2 Research methodologies

For the generation of this model, we tried to follow the construction drawings of the building as much as possible; in addition to this, periodic visits were made to determine and corroborate the heights, sections of the structural elements and the distances between axes. For the masonry, a detailed survey was carried out to ensure the accuracy of the model.

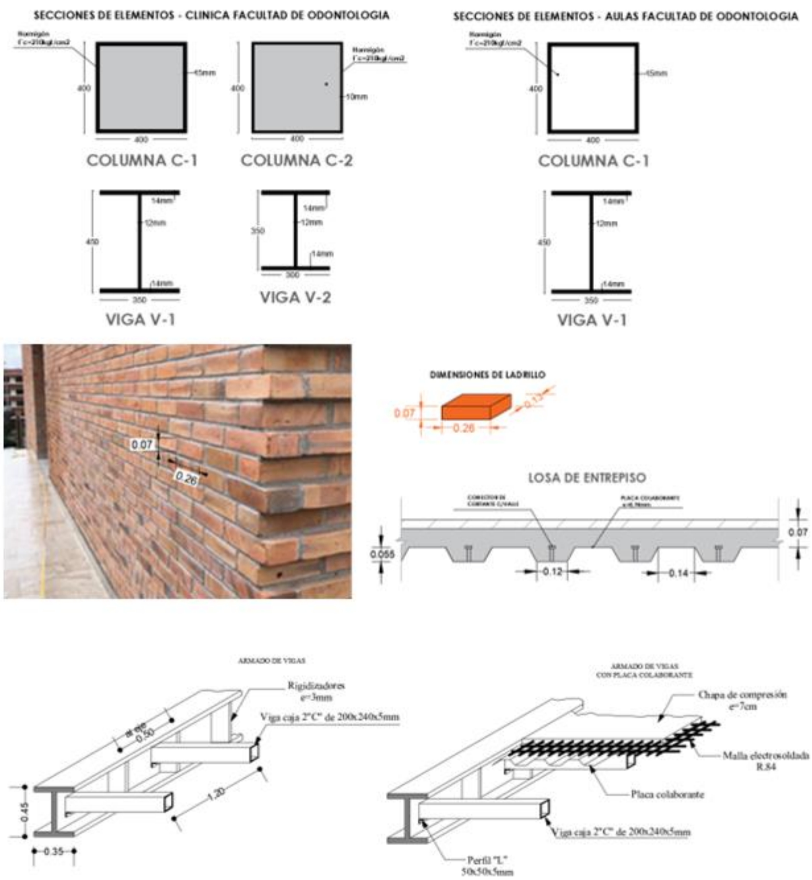


**Fig. 1.** Construction details considered in the computational model.

A summary of the loads used in the computational models is presented below.

**Table 1.** Dead loads in slabs.

| Permanent load on slab | | |
|---|---|---|
| W installations | 10 | kg/m$^2$ |
| W ceramics | 20 | kg/m$^2$ |
| W underlayment H.S (e=2,5cm) | 55 | kg/m$^2$ |
| W gypsum board for each mm of thickness | 0.8 | kg/m$^2$ |
| W gypsun plaster and suspended metal laths | 48.82 | kg/m$^2$ |
| TOTAL | 134.62 | kg/m$^2$ |

In addition, the calculation of the masonry loads was made to enter them into the program in a linear way on the beams and on the slabs were entered per square meter. The calculation of the slab self-weight was performed automatically by the program based on the geometric characteristics of the collaborating slab and the concrete on the slab, which were manually verified in spreadsheets. The live loads were taken from the NEC-SE-CG.

## 2.1 Environmental vibration test

### *2.1.1 Equipment used*

The Raspberry Shake RS3D seismograph was used for environmental vibration monitoring. The seismograph has three high-precision sensors that allow the detection of signals in the north-south (N-S) and east-west (E-W) directions, and in the vertical direction [9]. A single sensor located at the top of the buildings will be used to obtain the environmental vibration records and to measure the accelerations by means of the seismograph. [10].

### *2.1.2 Data extraction*

The data extraction is done through the FILEZILLA application. This application allows us to enter the Raspberry repository and download the data quickly from the server.

In this web application we are going to configure the equipment and put it offline since we do not have internet cabling for the test.

Once the data are extracted, they are loaded into the SWARM program.

The data must be converted from counts to acceleration, for this we use Excel software. The conversion is done in order to analyze the data in geopsy. The time value is placed with an interval of 0.01s and the counts value is transformed to acceleration using the factor 386825. This factor converts counts to m/s2. This value is given by the equipment itself.

For the calculation of the natural frequency of vibration we use the program geopsy. This program will help us to analyze the frequency spectrum as a function of time and acceleration.

The first step to follow is to correct the line of zeros and assign the exact time when the vibration test was performed with the equipment. The hamming method will be used.

**Fig. 2.** Location of the Raspberry on the terrace of the Dental Clinic.

## 3 Building 1 - Faculty of dentistry clinic

## 3.1 ETABS model

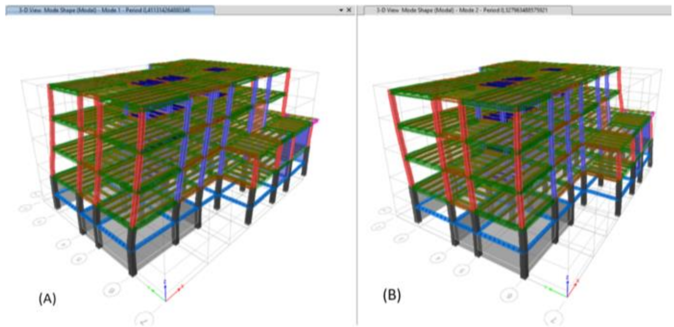

**Fig. 3.** Analytical model of Building 1, Dental Clinic. Fig. A shows vibration mode 1, which is in the X direction. Fig. B shows vibration mode 2 in Y direction. Source ETABS.

In the previous figure we observe building 1 in a 3D visualization where the direction of the deformation of mode 1 and mode 2 can be seen, also the masonry that was modelled as wall type can be seen and only the masonry located between main axes and that do not have openings was taken into account, so that it provides stiffness to the system, this with the objective of simulating the real dynamic behaviour of the structure with all the elements that provide stiffness and those that provide mass, the structure has a period of 0.41 in X and 0.33 in Y.

## 3.2 Environmental vibration analysis

The raspberry was placed on the terrace of the building, specifically in the center to capture the highest accelerations in order to obtain representative data for their respective analysis. The environmental vibration analysis yielded the following graph:

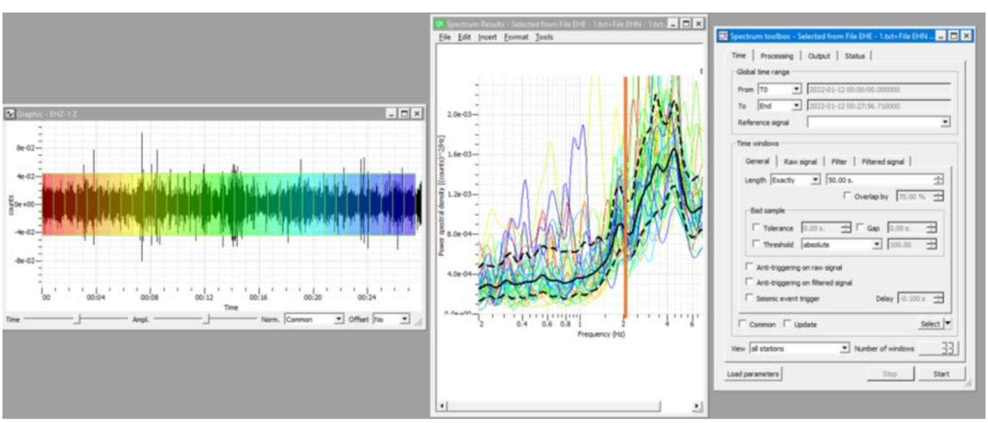

**Fig. 4.** Frequency in X building 1, Dental Clinic. Source Geopsy

The figure above shows a frequency of 2.13 Hz. Which transformed to period would be equivalent to 0.468s.

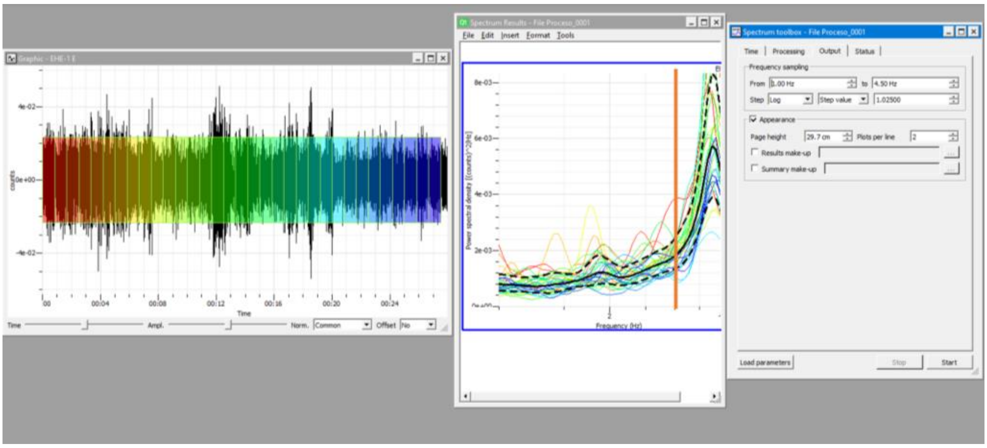

**Fig. 5.** Frequency in Y building 1, Dental Clinic. Source Geopsy

The above graph shows a frequency of 3.336 Hz. Which transformed to period will be equivalent to 0.30 sec.

## 4 Building 2 - School of Dentistry Classrooms

### 4.1 ETABS model

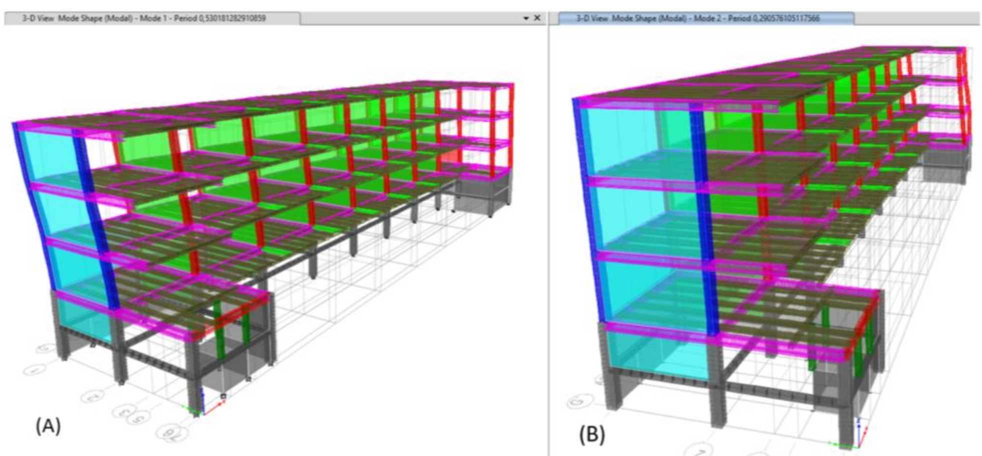


**Fig. 6.** Analytical model of Building 2, Dentistry Classrooms. Fig. A shows vibration mode 1, which is in the X direction. Fig. B shows vibration mode 2 in Y direction. Source ETABS.

In the previous figure we observe building 2 in a 3D visualization where the main vibration modes of the structure can be seen, also the location of the masonry can be seen, which is a wall type model and only the masonry located between main axes and that do not have openings was taken into account, in order to provide stiffness to the system. The structure has a period of 0.53 sec in X and 0.29 sec in Y.

### 4.2 Environmental vibration analysis

The environmental vibration analysis yielded the following graph:

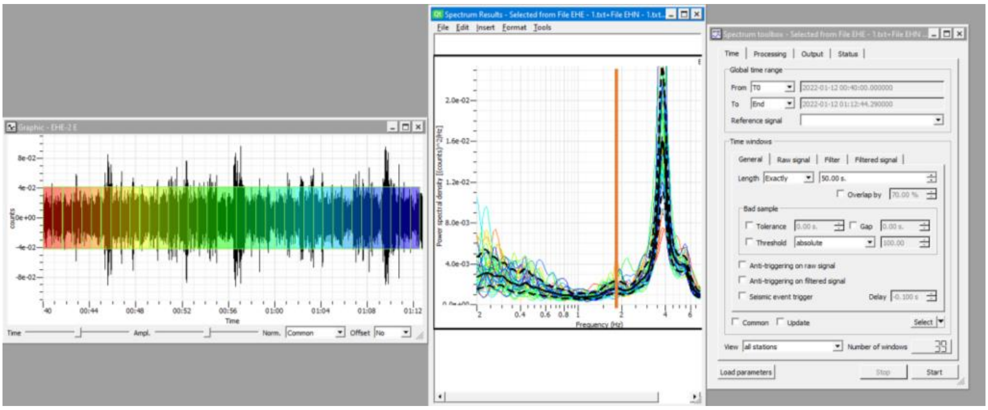


**Fig. 7.** Frequency in X building, Dentistry Classroom. Source Geopsy

The above graph shows a frequency of 1.91 Hz. Which transformed to period would be equivalent to 0.523s.

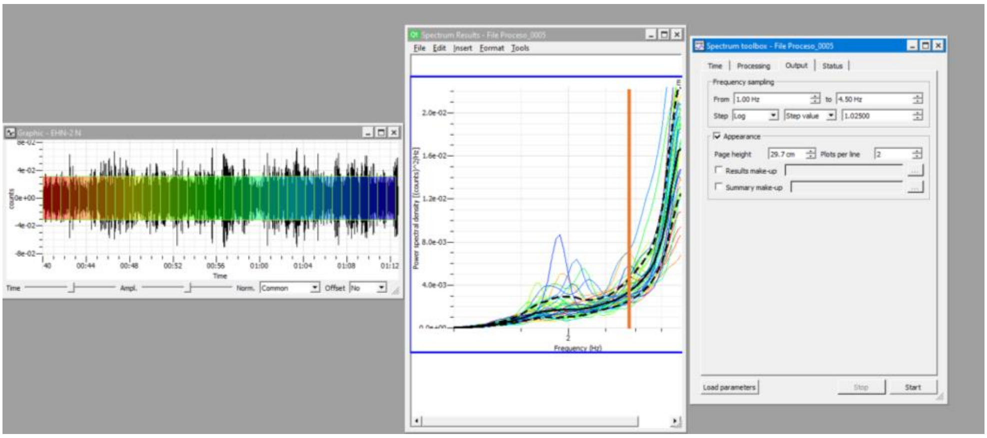


**Fig. 8.** Frequency in Y building, Dentistry Classroom. Source Geopsy

The figure above shows a frequency of 3.84 Hz. Which transformed to period would be equivalent to 0.26s.

### 5 Comparison of results

Tables 2 and 3 show the values obtained for the analytical and experimental vibration periods and their respective error in percentage.

**Table 2.** Periods of vibration in the Dental Clinic building.

| Address | Analytical Period | Experimental Period | % |
|---|---|---|---|
| X | 0,41 | 0,46 | 10,87 |
| Y | 0,33 | 0,3 | 9,09 |

**Table 3.** Periods of vibration in dental classrooms.

| Address | Analytical Period | Experimental Period | % |
|---|---|---|---|
| X | 0,53 | 0,52 | 1.88 |
| Y | 0,29 | 0,26 | 10.34 |

## 6 Conclusions

In building 1, Dentistry Clinic, the vibration periods obtained analytically are Tx= 0.41 sec (2.43 hz) and Ty=0.33sec (3.03 hz), while the periods obtained from environmental vibration signals are Tx=0.46sec (2.17hz) and Ty=0.30sec (3.33hz). Comparing the results in an analytical and experimental way we observe differences of 10.87% in the X direction, being greater the values obtained in the vibration period in an experimental way, in the Y direction we have differences of 9.09%, being the analytical period greater than the experimental one.

The dentistry clinic is more flexible in the X direction, due to the fact that in the Y direction there are masonry walls that contribute to the lateral stiffness of the building.

In building 2, Dentistry classrooms, the vibration periods obtained analytically are Tx= 0.53 sec (1.89 Hz) and Ty=0.29 sec (3.45 Hz), while the periods obtained from environmental vibration signals are Tx= 0.52 sec (1.92 Hz) and Ty=0.26 sec (3.85 Hz). Comparing the results in an analytical and experimental way we observe differences of 1.89 % in the X direction, being slightly higher the values obtained in the analytical period, in the Y direction we have differences of 10.34%, being the analytical period higher than the experimental one.

The odontalgia classroom building is more flexible in the X direction, due to the fact that in the Y direction there are masonry walls that contribute to the lateral stiffness of the building, as long as the structure is in the elastic range.

The period was also obtained approximately using the criteria of the NEC-SE-DS section 6.3.3 where the period is obtained based on the height of the building and other parameters according to the type of structure and in this case a period of 0.58 sec was obtained, the analytical and experimental vibration periods are lower than those obtained based on the NEC.

Building 2, dentistry classrooms, has a geometry with a marked length/width ratio = 6. 30, being all the columns of the same dimension, and having a weak axis that is in the Y direction, which is not corroborated in the analytical or experimental vibration periods, this because the masonry located between axes in the Y direction provides stiffness to the system, in a greater way in this direction, so the vibration period in this direction is lower, the analysis is performed in the elastic range, if the elastic range is exceeded, the masonry could crack and change the dynamic behavior of the structure.

According to the equation for calculating the vibration period: $\boldsymbol{T = 2\pi * \sqrt{\frac{m}{k}}}$ , it can be seen that stiffness is a determining parameter, since for any variation in stiffness there will be a variation in the period, the analyzed structures have a short useful life and have not suffered strong ground excitations, due to this the structural and non-structural elements have not suffered any damage, This research is the basis to obtain an estimation of the vibration periods that could be called initial without the structure having suffered deterioration or any type of cracking in its elements, a continuous monitoring system should be implemented to record excitations produced by earthquakes and to have a record of the dynamic behavior and to appreciate the possible variations of the vibration period due to the degradation of the stiffness that could occur due to strong ground movements.

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